Nitrogen Management to Help Reduce GHG Emissions

C.S. Snyder, A.M. Johnston, and P.E. Fixen

Global Human Family and N_2O Emissions

- **Global population: 9 billion expected by 2050**
- **Agriculture accounts for 10 to 15% of global GHGs**
  - Agriculture: ~ 60% of N_2O and 50% of CH_4 (Flynn & Smith , 2010)
  - China>India>EU-25>USA>Brazil: largest agricultural emitters
- **Fertilizer N use and application:**
  - **Canada 47%, U.S. 28%, EU-15 27%** of direct ag soil management related N_2O emissions in 2007 (Environ. Canada, U.S. EPA, and EEA; 2009)
  - **India 60%** of direct and indirect N_2O emissions from all economic sectors in in 2005 (Garg et al. 2006)
  - **Global fertilizer N use:** 110 MT expected by 2013 (IFA, 2010)
- **Agricultural N_2O emissions expected to increase by 35 to 60% by 2030, in association with increased fertilizer N use and manure production** (Smith et al., 2007, IPCC)

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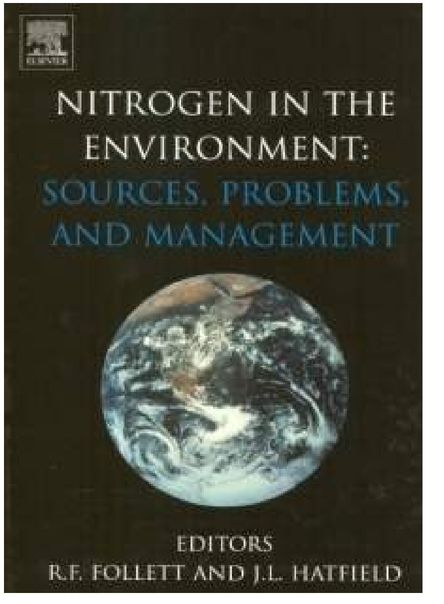
Global Nitrogen Use Efficiency, Expressed as Apparent N Recovery (RE_N)

- $\leq$50% N use efficiency globally by most crops (Balasubramanian et al., 2004; Ladha et al., 2005)
- typical on-farm RE_N (Dobermann and Cassman, 2002)
  - only 30% in rice and 37% in maize,
  - with good management RE_N could be 50 to 80%
- in cereal crop research
  - total RE_N from a one-time application of N averages 50 to 60%, and 40 to 50% under most on-farm conditions (Dobermann, 2007)

Kitchen and Goulding (2001) *in* Nitrogen in the Environment: Sources, Problems and Management

- **“ nitrogen use efficiency …rarely exceeds 70% ……. often ranges from 30-60%”**
- **“conversion of N inputs to products for arable crops can be 60-70% or even more”**



U.S. EPA SAB Integrated N Committee report on reactive N (May 28, 2010 DRAFT): “… finds that crop N-uptake efficiencies can be increased by up to 25% over current practices through a combination of knowledge-based practices and advances in fertilizer technology (such as controlled release and inhibition of nitrification).”

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"Back of the Envelope" Calculations for U.S.

- **3.6% of U.S total GHGs** = Ag soil management N_2O emissions
  - 6,956.8 Tg CO_2-e x 0.036 = **250 Tg CO_2-e (0.25 Gt CO_2-e)**
- **Potential direct N_2O emission reduction impacts with improved crop N uptake**
  - if one assumes that a 25% increase from current RE_N translates to a 25% reduction in ag soil management N_2O emissions ….
    - 0.75 x 250 = **188 Tg CO_2-e (0.19 Gt CO_2-e)**
    - or about **2.7% of total annual CO_2-e GHG emissions**
- **With such a small potential impact, why is there so much focus on agriculture's fertilizer N consumption?**
  - potential impact of larger combined direct and indirect N_2O emissions
  - "bang for the buck" in trading and mitigation schemes (i.e. 296x CO_2-e emission factor for N_2O)

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N_2O Emissions from Global Fertilizer N Consumption, with IPCC 1% Emission Factor

	1990	1995	2000	2005
	million metric tons (MT)			
Fertilizer N	76.78	78.23	82.07	92.93
N_2O (using 1% N_2O-N EF)	1.21	1.23	1.29	1.46
IPCC N_2O, CO_2-equiv.	**357**	**364**	**382**	**432**
Global total N_2O from all sources, CO_2-e	2,871	2,915	3,114	3,286
Global total GHGs from all sources, CO_2-e	39,000	--	41,382	44,153
Fertilizer N_2O (CO_2-e) as % of global total CO_2-e N_2O	**12**	**12**	**12**	**13**
Fertilizer N_2O (CO_2-e) as % of global total CO_2-e GHGs	**0.92**	**--**	**0.92**	**0.98**

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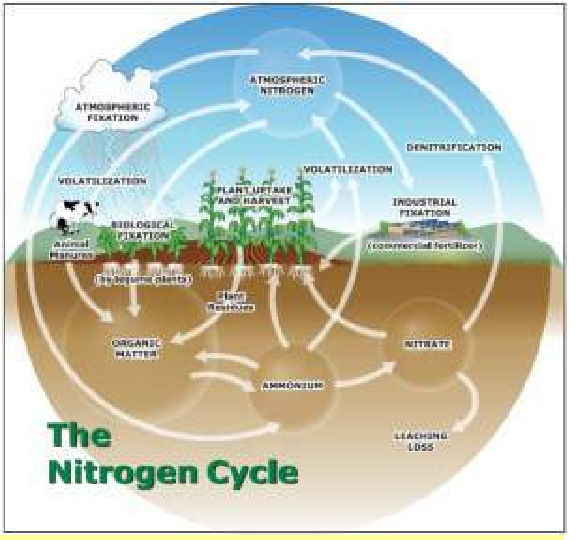
Fertilizer N Use Efficiency is Affected by

- N supply from:
  - Soil
  - Fertilizer
  - Other inputs
- Crop N uptake
- N losses from the soil–plant system
  - Volatilization, leaching, runoff, denitrification (and nitrification)
- All are affected by cropping system management and environmental conditions



Cropland Management Measures to Help Mitigate GHGs

- Cropland management, which includes nutrient management, has a GHG mitigation potential approaching 1,600 MT CO_2-equivalent/yr

	Mitigative effects[a]			Net mitigation[b] (confidence)	
Examples	**CO_2**	**CH_4**	**N_2O**	**Agreement**	**Evidence**
Agronomy	+		+/-	***	**
Nutrient management	+		+	***	**
Tillage/residue management	+		+/-	**	**
Water management (irrigation, drainage)	+/-		+	*	*
Rice management	+/-	+	+/-	**	**
Agro-forestry	+		+/-	***	*
Set-aside, land-use change	+	+	+	***	***

Smith et al. 2007. Agriculture. In Climate Change 2007: Mitigation. IPCC

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Global Nutrient Management Potential to Mitigate GHGs from Croplands,
reported by Flynn and Smith, 2010

Climate Zone	CO_2 mean	CH_4 mean	N_2O mean	GHG sum mean	GHG range
	tons CO_2-equivalent ha^{-1} yr^{-1}				
Cool dry	0.26	0	0.07	0.33	-0.21 - 0.71
Cool moist and warm moist	0.55	0	0.07	0.62	0.02 - 1.42
Warm dry	0.26	0	0.07	0.33	-0.21 - 1.05

"Mean and uncertainty for change in soil C, N_2O and CH_4 emissions are at the climate region scale, and are not intended to reflect finer scales such as individual farms."

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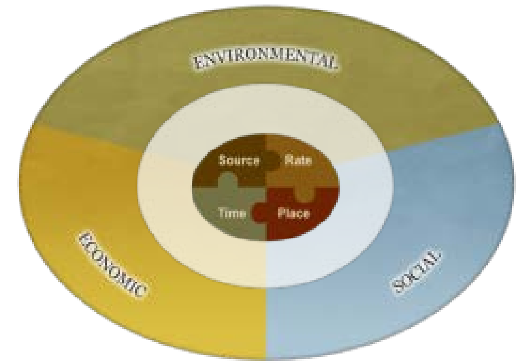
4R Nutrient Stewardship

Know your fertilizer rights

By Tom Bruulsema, International Plant Nutrition Institute, Guelph, ON, Canada; **_Jerry Lemunyon_**, USDA-NRCS, Fort Worth, TX; and **_Bill Herz_**, The Fertilizer Institute, Washington, DC

Crops & Soils 42(2): Mar-Apr 2009



http://www.ipni.net/4r

The four fertilizer rights: Selecting the right source

By Robert Mikkelsen, International Plant Nutrition Institute, Merced, CA; **_Greg Schwab_**, University of Kentucky, Lexington; and **_Gyles Randall_**, University of Minnesota, Waseca

Crops & Soils 42(3): May-Jun 2009

Selecting the right fertilizer rate: A component of 4R nutrient stewardship

By S.B. Phillips, International Plant Nutrition Institute, Owens Cross Roads, AL; **_J.J. Camberato_**, Purdue University, West Lafayette, IN; and **_D. Leikam_**, Fluid Fertilizer Foundation, Manhattan, KS

Crops & Soils 42(4): Jul-Aug 2009

The four fertilizer rights: timing

By W.M. Stewart, International Plant Nutrition Institute, Norcross, GA; **_J.E. Sawyer_**, Iowa State University, Ames, IA; and **_M.M. Alley_**, Virginia Tech, Blacksburg, VA

Crops & Soils 42(5): Sep-Oct 2009

Know Your Fertilizer Rights: Right Place

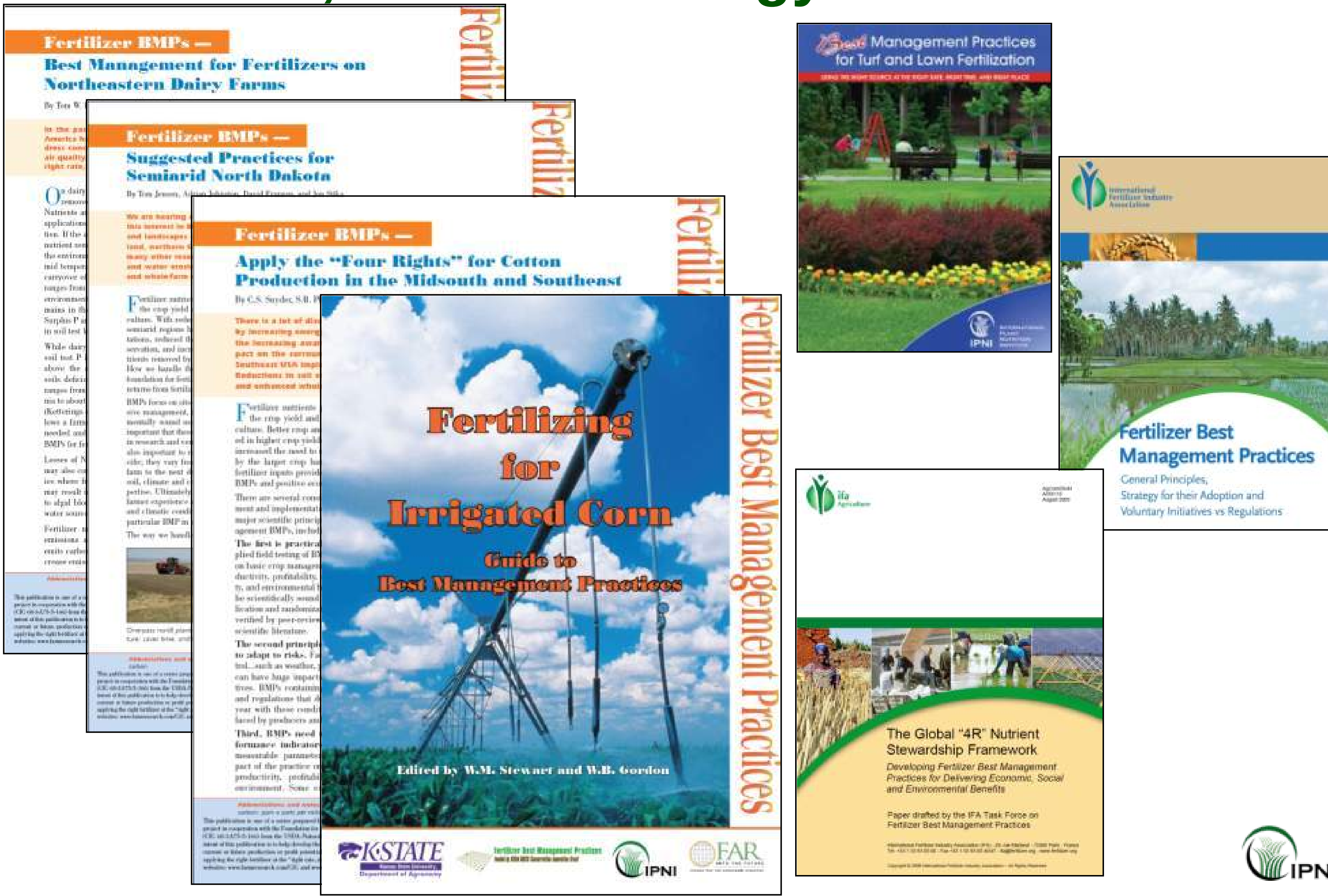
by T.S. Murrell (IPNI), G.P. Lafond (AAFC), and T.J. Vyn (Purdue U.)

Crops & Soils 42(6): Nov-Dec 2009

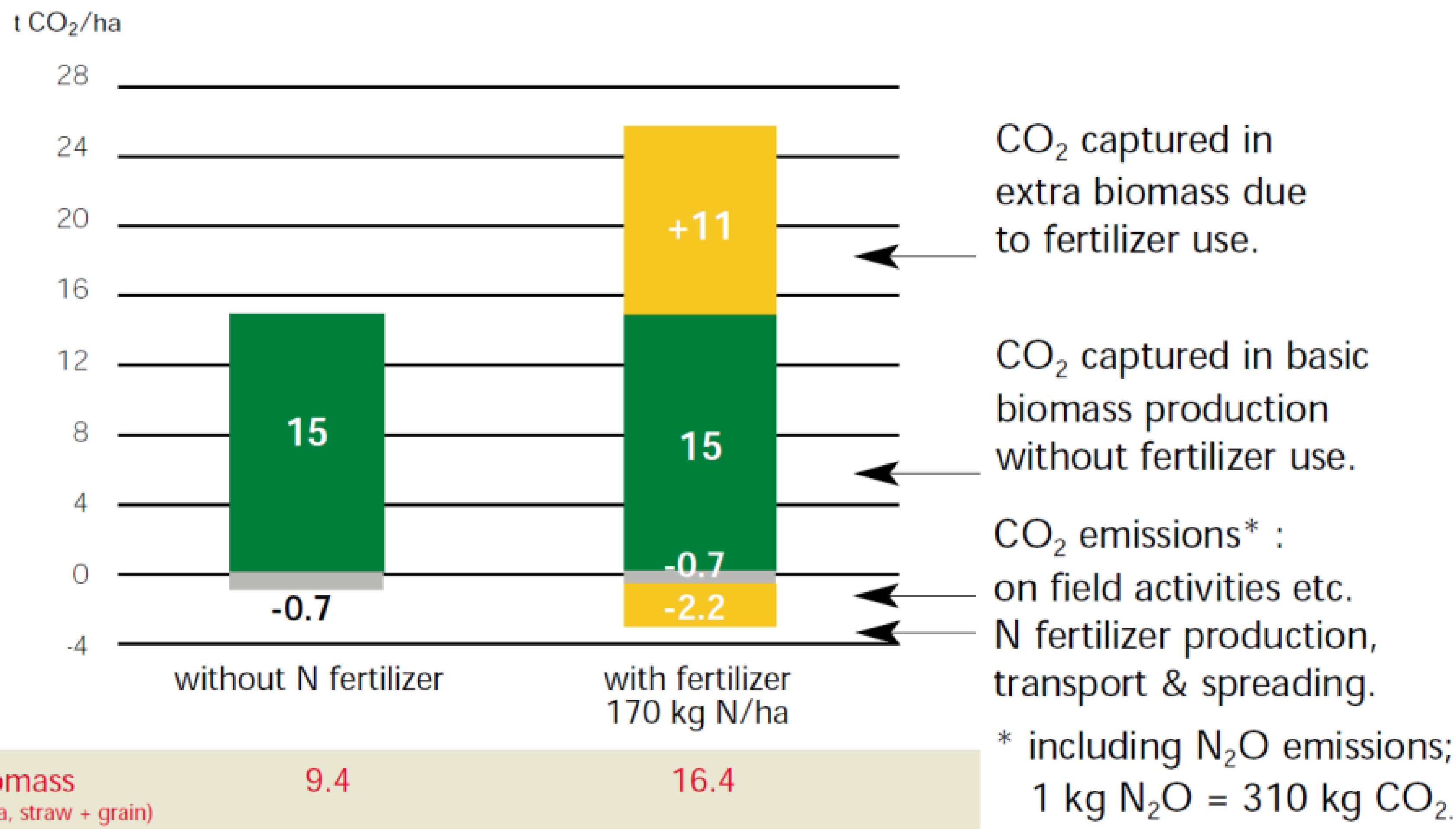
Soil and Fertilizer Management Can Help Reduce GHG Emissions

- **Through wider implementation of "4R" BMPs:**
  - **But requires**
    - more research to evaluate optimum "Rs"
    - more education and technology transfer to hone nutrient management skills of crop advisers and farmers
  - **And should be coupled with**
    - appropriate conservation tillage practices
    - optimum irrigation practices, and soil drainage management
    - improved genetics and seed technology

Intensified Fertilizer BMP Education, Outreach, and Technology Transfer



CO_2 fixed on 1 ha wheat



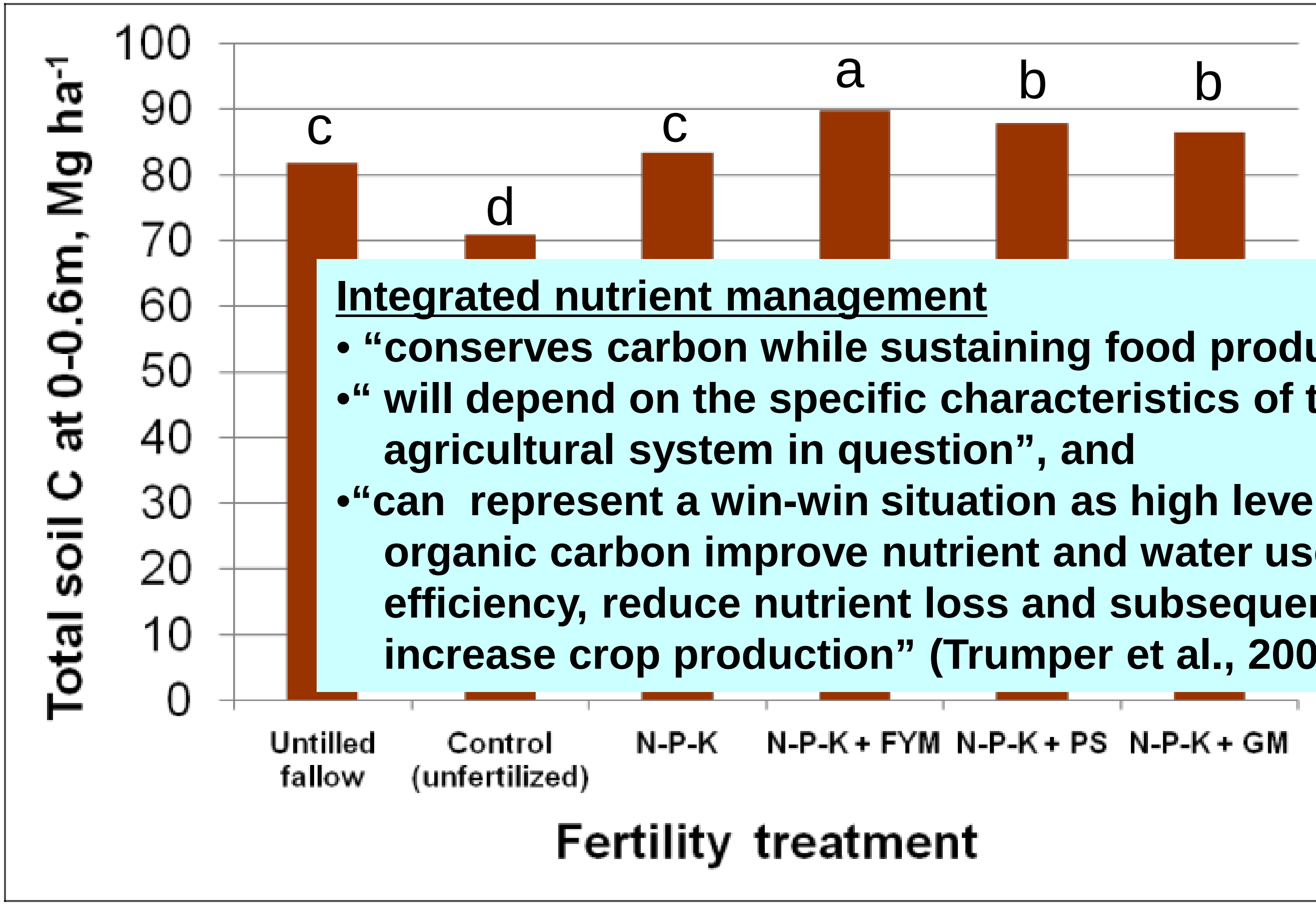
	without N fertilizer	with fertilizer 170 kg N/ha
Biomass (t/ha, straw + grain)	9.4	16.4

Source : Data taken from Küsters and Lammel, 1999.

Cited by EFMA, 2008. Harvesting Energy with Fertilizers

Fertilization and Organic Matter Effects on Total Soil Carbon after 19 Years in Rice-Wheat Rotation

India



<u>Integrated nutrient management</u>

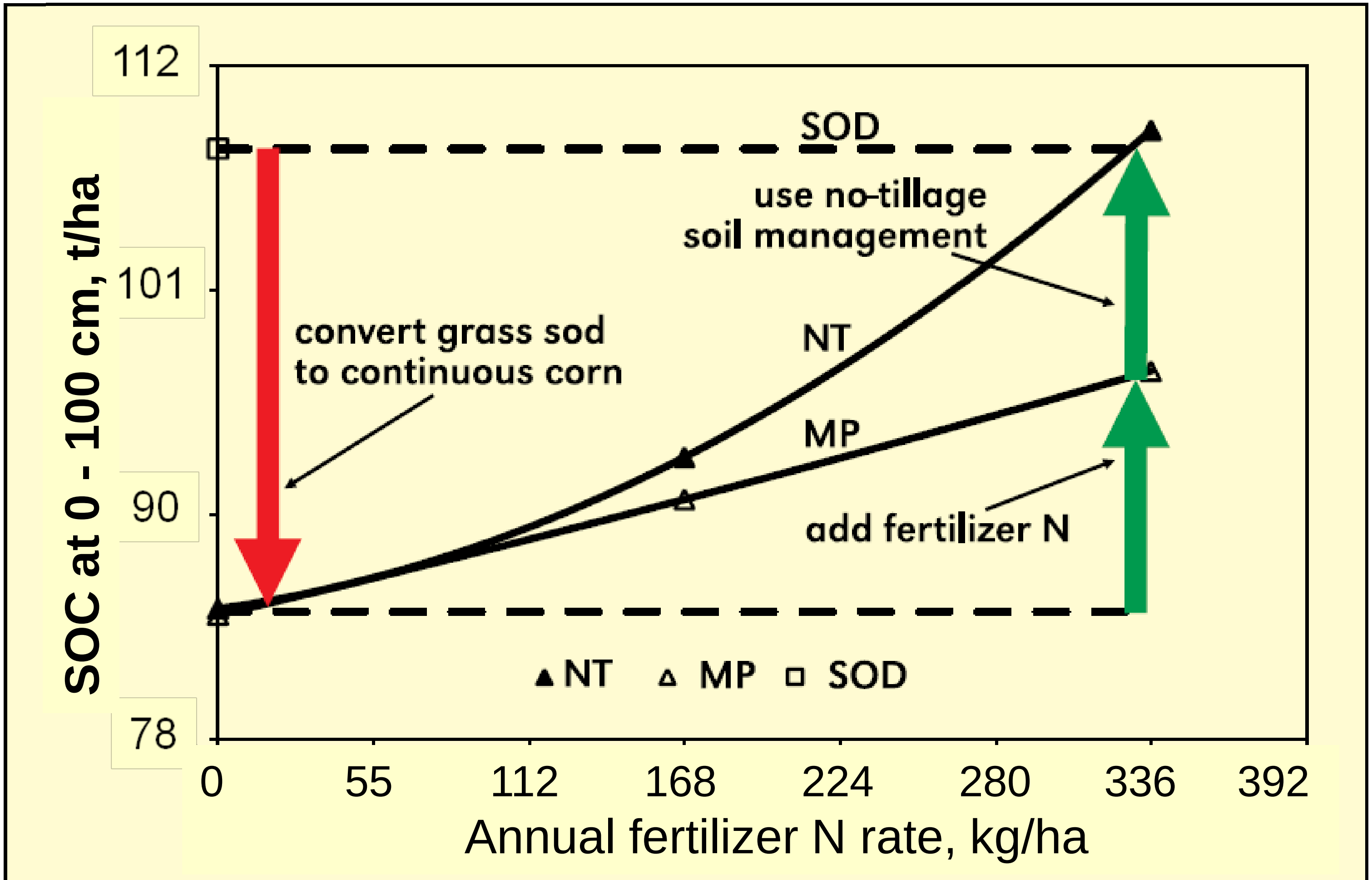
- **"conserves carbon while sustaining food production",**
- **" will depend on the specific characteristics of the agricultural system in question", and**
- **"can represent a win-win situation as high levels of soil organic carbon improve nutrient and water use efficiency, reduce nutrient loss and subsequently increase crop production" (Trumper et al., 2009)**

•FYM= farm yard manure (7.5 Mg ha^{-1}), PS=paddy straw (10 Mg ha^{-1}), GM=green manure (8 Mg ha^{-1}), all on wet-weight basis

•120–60–60 kg ha^{-1} ($N–P_2O5–K_2O$) for rice and 100–60–40 kg ha^{-1}($N–P_2O5–K_2O$) for wheat

Majumder et al. 2008. Soil Sci. Soc. Am. J. 72:775-785

Fertilizer N Effects on Profile SOC After 39 Years of Continuous Corn with a Winter Cereal Cover Crop



Grove et al. 2010. Better Crops 93(4):6-8

P and K Fertility Condition of Sampled Soils in the U.S., China, and India and Median Soil Test Levels in North America (adapted from Fixen et al. 2005)

	Plant available soil P			Plant available soil K		
Level	**U.S.**	**China**	**India**	**U.S.**	**China**	**India**
	% of soil samples			% of soil samples		
Low	24	46	46	14	58	13
Medium	23	25	49	29	18	53
High	53	29	5	57	23	34

North America [a]		
	Median soil test P ($mg\ kg^{-1}$)	**Median soil test K ($mg\ kg^{-1}$)**
2001	**27**	**154**
2005	**31**	**154**
2010	**25**	**150**

% of soil samples with ≤ 25 $mg\ kg^{-1}$ soil test P in 2010	**50**	% of soil samples with ≤ 160 $mg\ kg^{-1}$ soil test K in 2010	**55**

Inadequate, or below optimum, P and K fertility limits crop production in much of the world and may also limit crop N uptake efficiency

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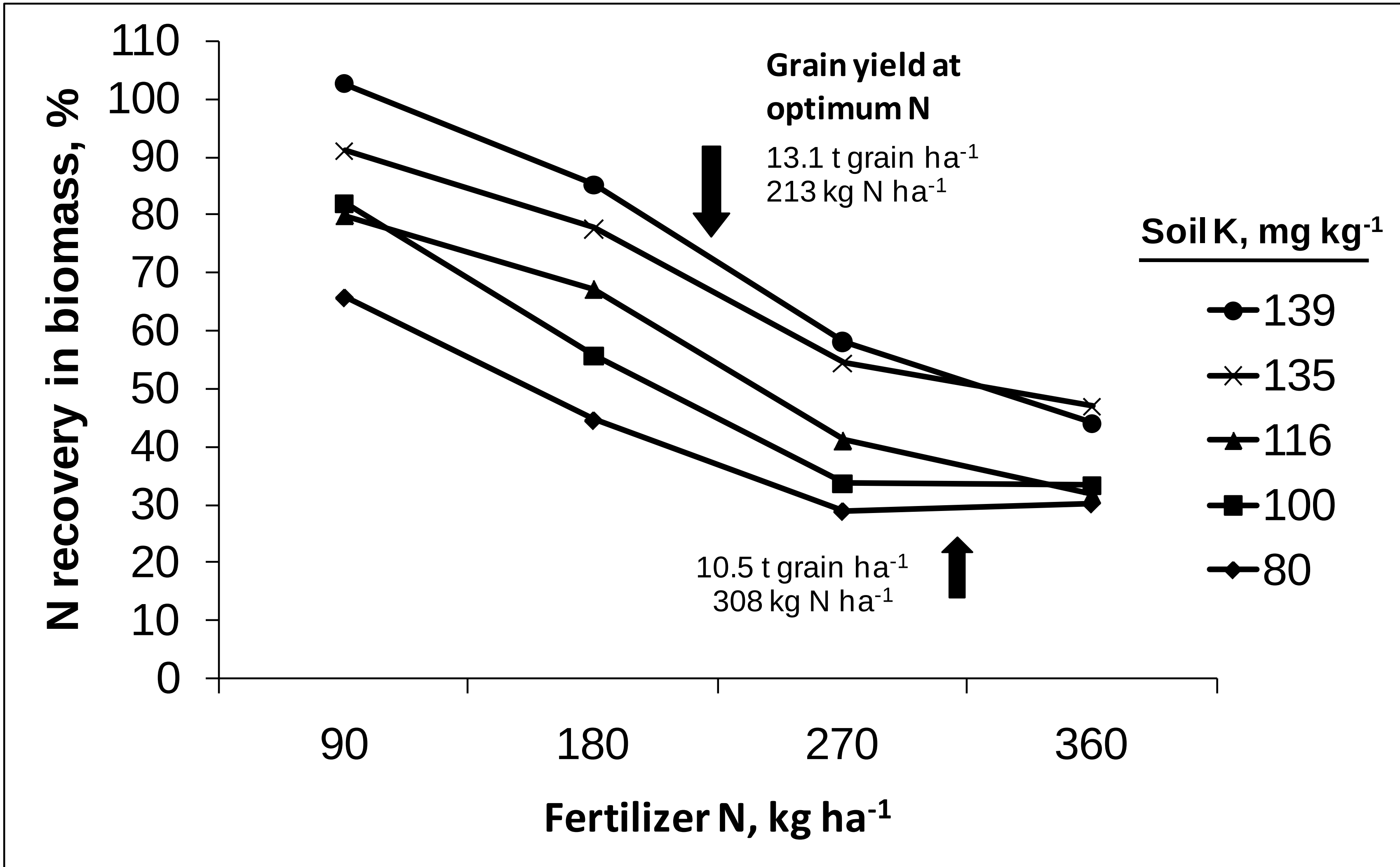
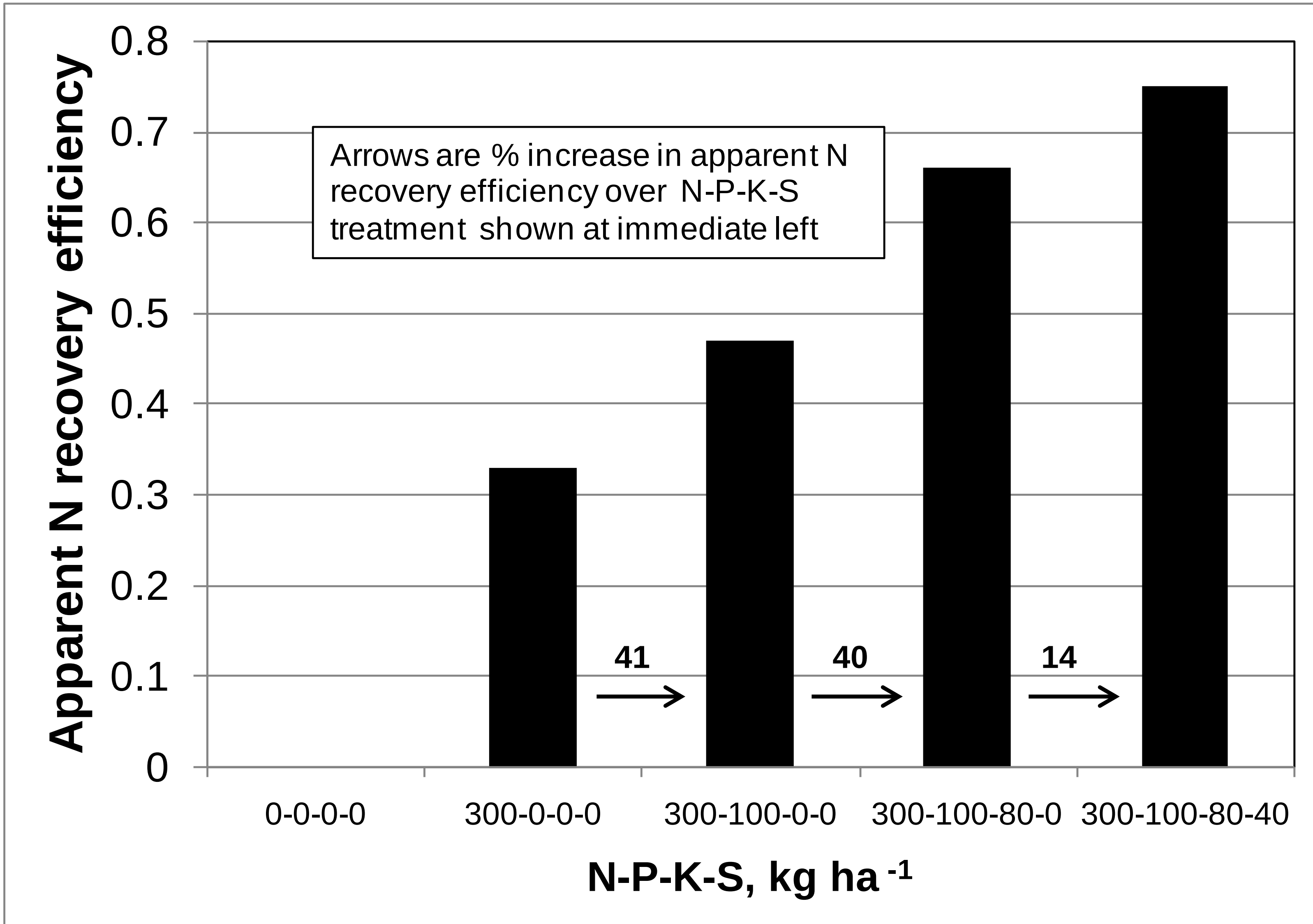
Effects of Proper K Fertilization on Apparent N Recovery by Maize

(Johnson et al., 1997. Ohio, U.S.)



Balanced Fertilization Effects on Apparent N Recovery by Maize (assuming 25 kg of N uptake per tonne of grain (Gordon, 2005. Kansas, U.S.))



Agriculture, Ecosystems and Environment (2009) 133:247-266.

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journal homepage: www.elsevier.com/locate/agee

Review

Review of greenhouse gas emissions from crop production systems and fertilizer management effects

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Fertilizer N : source, rate, timing, and place of application

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Range of N_2O Emission Among N Sources can Vary Greatly

- **Report 1** (Stehfest & Bouwman, 2006)
  - 0 to 46% of applied N
- **Report 2** (Granli & Bockman, 1994)
  - 0 to 7% of applied N
- **Report 3** (Eichner, 1990)
  - 0 to 7% of applied N

- **Report 1**
  - **Median** among N sources ranged from: **0.26 to 1.56 kg of N/ha**

Snyder et al. 2009. Agric. Ecosyst. Environ. 133:247-266

Summary of N_2O Emissions Induced by Common Fertilizer N Sources (based on Bouwman et al. (2002a, 2002b) and Stehfest and Bouwman (2006))

	Mean fertilizer induced emission [1]		Balanced median emission [2]	
N source	n	N_2O as % of applied N	n	kg N_2O-N ha^{-1}
calcium ammonium nitrate	61	0.7	73	1.56a[3]
ammonium nitrate	59	0.8	131	1.12a
anhydrous ammonia	38	0.9	38	1.04a
nitrate-based fertilizers [4]	53	0.9	53	0.80b
urea ammonium nitrate (solutions)	37	1.0	40	0.78b
urea	98	1.1	131	0.96b
ammonium-based fertilizers [5]	59	1.2	74	0.82b
IPCC default		*1*		

[1]Bouwman et al. 2002a, 2002b
[2] Stehfest and Bouwman 2006
[3] Values followed by a common letter are not significantly different, based on two-tailed statistical tests (Stehfest and Bouwman 2006)
[4]Includes potassium nitrate, calcium nitrate, sodium nitrate (Bouwman et al. 2002a, 2002b)
[5]Includes ammonium bicarbonate, ammonium chloride, ammonium sulfate (Bouwman et al. 2002a, 2002b)

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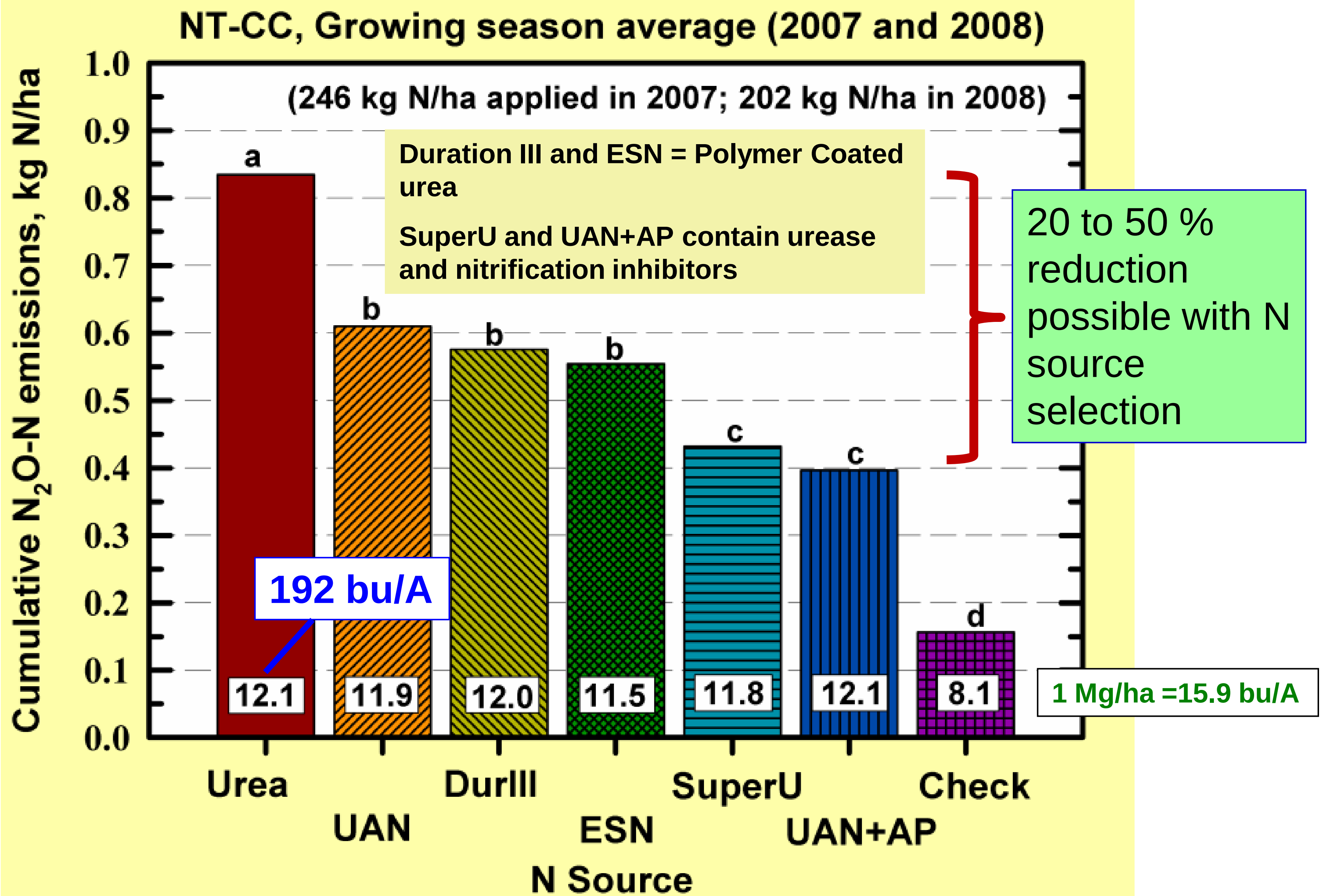
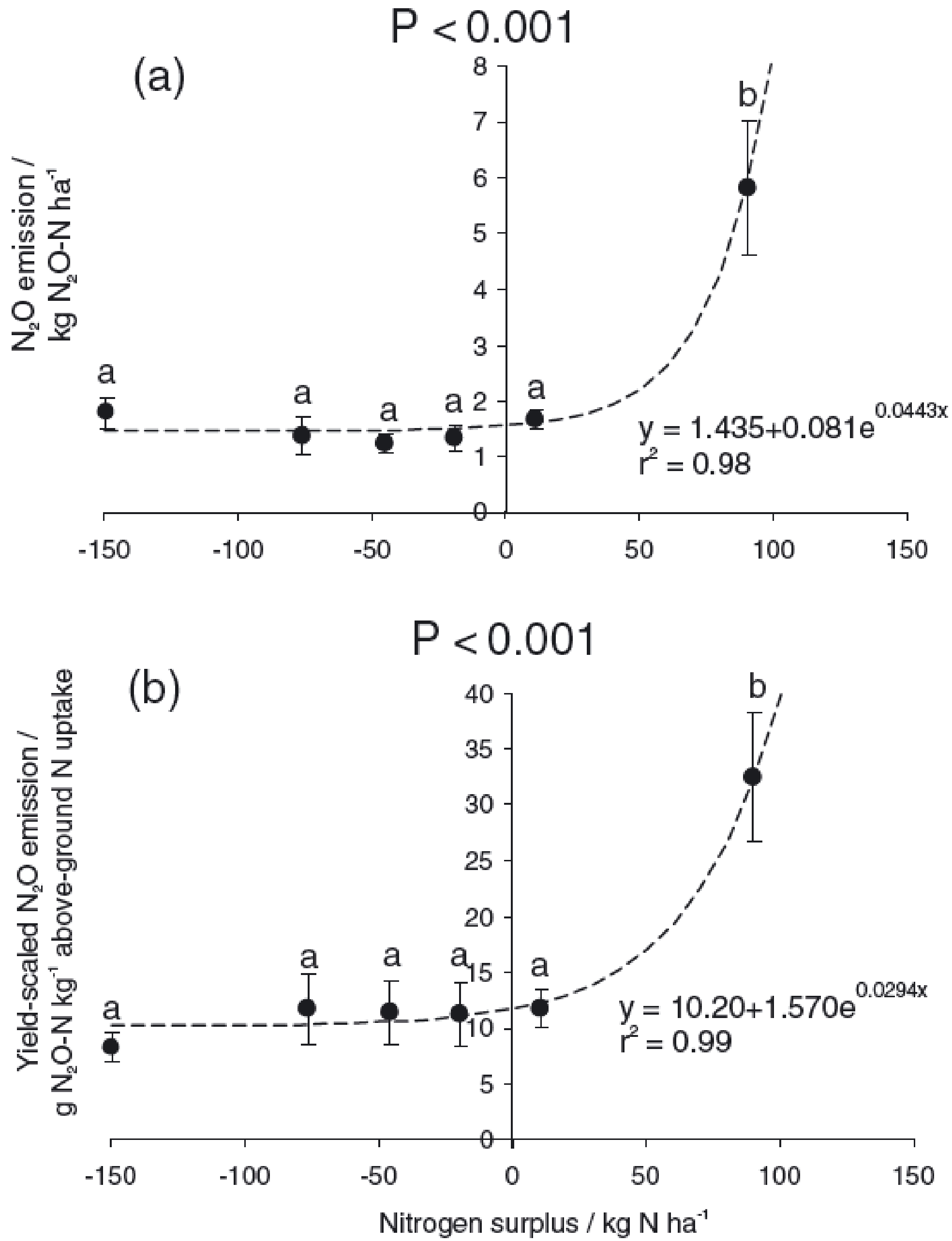


Corn grain yield (Mg/ha) is shown near the bottom of each bar

Source: Halvorson et al., 2009. Better Crops 93(1):16-18; J. Environ. Qual. 2010. 39:1554–1562



The Key is to Limit Potential "Surplus N"

" … agricultural management practices to reduce N_2O emissions should **focus on optimizing fertilizer-N use efficiency under median rates of N input**, rather than on minimizing N application rates."

Van Groenigen et al. 2010. Europ. J. Soil Sci. doi: 10.1111/j.1365-2389.2009.01217.x

Earlier Work with Nitrification Inhibitors and PCU Sources of N on N_2O Emissions

- Bronson, Mosier, and Bishnoi (1992) – corn (Colorado)
  - Nitrification inhibitor (nitrapyrin) reduced urea emissions 40-65%
- Delgado and Mosier (1996) – barley (Colorado)
  - 0 to 21 d after fertilization, emissions reduced by 82% and 71% with nitrification inhibitor (DCD) and PCU
  - N_2O emission was higher remainder of season with PCU
- Shoji, Delgado, Mosier, and Miura (2001)
  - barley (Colorado)
    - nitrification inhibitor (DCD) and PCU (Meister N) reduced N_2O emissions from urea by 81% and 35% (low emissions: 0.07, 0.24, 0.37% of N applied for DCD, PCU and urea treatments)
  - corn on a loamy soil (lysimeter in Japan)
    - total N_2O emissions reduced 66% with PCU vs. urea

Bronson et al. 1992. Soil Sci. Am. J. 56:161-165; Delgado and Mosier.1996. J. Environ. Qual. 25:1105-1111; Shoji et al. 2001. Comm. Soil Sci. Pl. Anal.32(7):1051-1070

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Timing of Application

- Saskatchewan, Canada
  - Hultgreen and Leduc (2003): emissions of N_2O were lower following spring N fertilizer application than following autumn application, with canola, flax, and wheat
- Alberta, Canada
  - Hao et al. (2001): wheat and canola @100 kg N/ha, significantly lower N_2O emissions with spring than with fall fertilizer N
- **Midwest U.S. - ?**
  - Millar et al. (2010): synchronous timing of N with plant N demand "is an important factor in determining soil N availability and, potentially, emissions of N_2O from row crop agriculture".

•**Mean reductions in N_2O emissions** – meta analyses (*Akiyama et al. 2010.Global Change Biology 16:1837–1846*):

•**nitrification inhibitors** - 38%

•**polymer coated urea** - 35%

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Place or Placement

- Breitenbeck and Bremner (1986) in Iowa, U.S.
  - anhydrous NH_3 (112 kg N/ha) injected at 30 cm had 107 and 21% greater N_2O emissions than injections at 10 and 20 cm.
  - effects of depth of application of anhydrous NH_3 on emission of N_2O was less @ of 225 kg N/ha
- Drury et al. (2006) in Ontario, Canada
  - ammonium nitrate (160 kg N/ha) sidedress at 2-cm depth had emissions 26% lower (2.8 kg N_2O-N/ha/yr), than with 10-cm placement (3.8 kg N_2O-N/ha/yr)
- Hultgreen and Leduc (2003) in Saskatchewan, Canada
  - urea banded below and to the side of the seed-row had lower N_2O emissions compared to surface broadcast urea in 2 of 3 years

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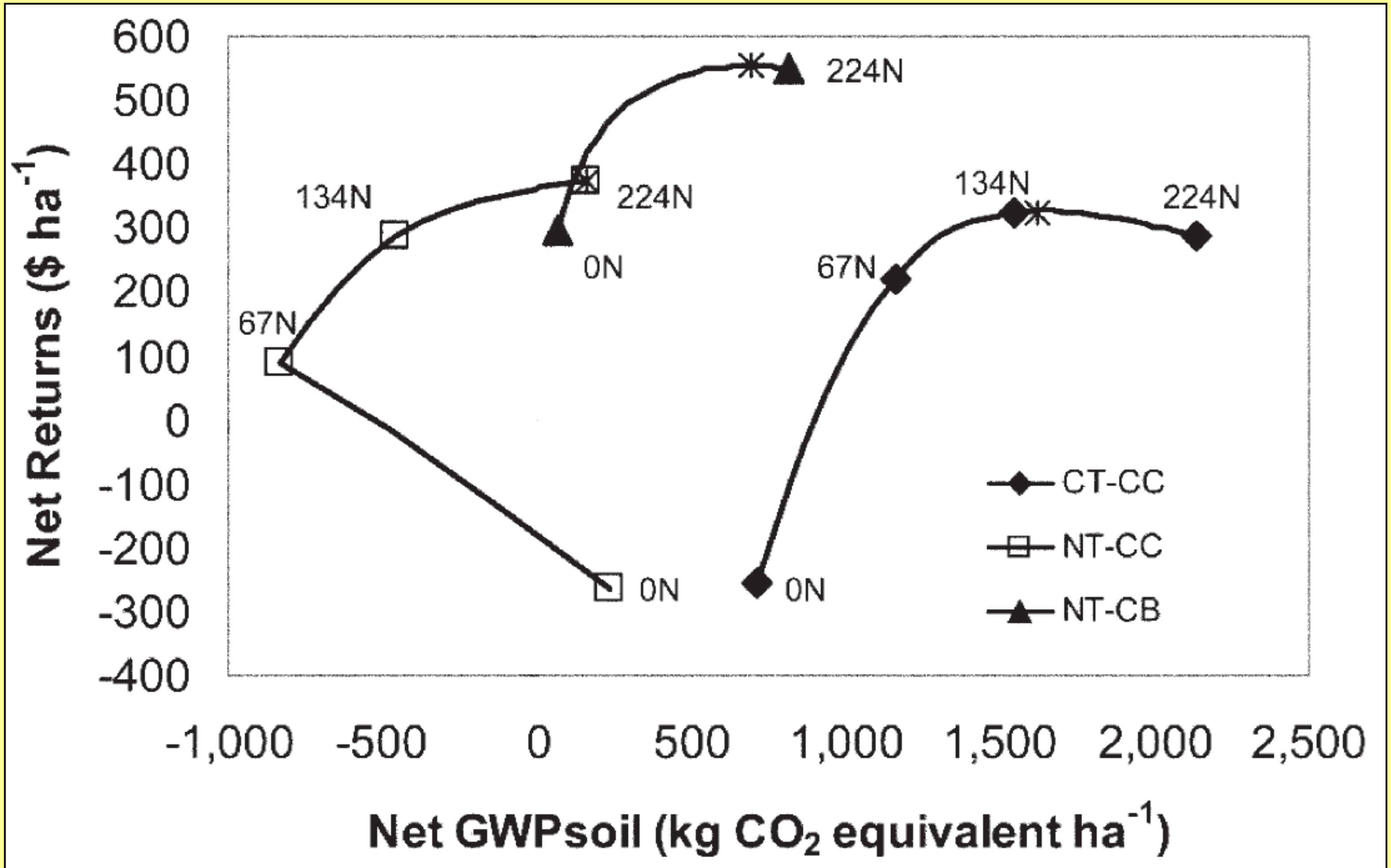
Costs Associated with Reductions of CO_2-e in Irrigated Corn Systems (CO)



Archer & Halvorson 2010. Better Crops 94(2):2-5; Soil Sci. Soc. Am. J. 74:446–452

Is Lower Input, Less Intensive Ag the Answer?

Table 3
Comparison of selected agricultural cropping systems for net global warming potential (GWP).

Cropping system	GWP in CO_2 equivalents (kg ha^{-1} $year^{-1}$)							Food yield[a] (Gcal ha^{-1} $year^{-1}$)	Mean crop yields (t ha^{-1})		
	Soil C[b]	N fert.[c]	Lime	Fuel	N_2O	CH_4	Net GWP		Corn	Wheat	Soybean
Robertson et al. (2000)—Michigan (9-year study)											
Corn–soybean–wheat rotation											
Conventional tillage	0	270	230	160	520	−40	1140	12	5.3	3.2	2.1
No-till	−1100	270	340	120	560	−50	140	13	5.6	3.1	2.4
Low-input with legume cover crop	−400	90	190	200	600	−50	630	12	4.5	2.6	2.7
Organic with legume cover crop	−290	0	0	190	560	−50	410	9	3.3	1.6	2.7
Perennial crops											
Alfalfa	−1610	0	800	80	590	−60	−200				
Poplar	−1170	50	0	20	100	−50	−1050				
Late succession forest	0	0	0	0	210	−250	−40				
Adviento-Borbe et al. (2007)—Nebraska (6-year study: non-inversion deep till system)											
Continuous corn at BMP	−1613	807	220	1503	1173	−110	1980	48	14.0		
Continuous corn—intensive	−2273	1210	330	1833	2090	−110	3080	51	15.0		
Corn–soybean rotation at BMP	1100	293	220	1283	917	−73	3740	35	14.7		4.9
Corn–soybean rotation—intensive	−73	660	330	1613	1247	−37	3740	37	15.6		5.0

[a] Food energy calculated from crop yields and USDA national nutrient database http://riley.nal.usda.gov/NDL/index.html.
[b] Estimate of net soil C storage are based on change in soil C measured to a depth of 7.5 cm in the Michigan study and 30 cm in the Nebraska study. Shallower sampling depths tend to upwardly bias the C sequestration estimates in no-till systems.
[c] Estimated GWP associated with fertilizer N manufacture and transport was 4.51 kg CO_2 kg^{-1} N in the MI study and 4.05 in the Nebraska study.

Snyder et al. 2009. Agric. Ecosyst. Environ. 133:247-266

More Intensive Systems Can Help Lower GWP per Unit of Food Produced

- Ecological Intensification -

State	Rotation & System	Tillage	Food Yield, Gcal/ha/yr		
MI	C-S-W	CT	12		
MI	C-S-W	NT	13		
MI	C-S-W low input w/legume	CT	12		
MI	C-S-W organic w/legume	CT	9		
NE	C-C BMP	CT	48		
NE	C-C intensive	CT	51		
NE	C-S BMP	CT	35		
NE	C-S intensive	CT	37		

Snyder et al. 2009. Agric. Ecosyst. Environ. 133:247-266

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More Intensive Cropping Systems Can Help Lower GWP per Unit of Food Produced

State	Rotation & System	Tillage	Food Yield, Gcal/ha/yr	N_2O GWP/Food Yield	Net GWP/Food Yield
MI	C-S-W	CT	12	43	95
MI	C-S-W	NT	13	43	11
MI	C-S-W low input w/legume	CT	12	50	53
MI	C-S-W organic w/legume	CT	9	62	46
NE	C-C BMP	CT	48	24	41
NE	C-C intensive	CT	51	41	60
NE	C-S BMP	CT	35	26	107
NE	C-S intensive	CT	37	34	101

4X more food

Snyder et al. 2009. Agric. Ecosyst. Environ. 133:247-266

	Real World (RW)		Alternative world (AW1)	Alternative world (AW2)
	Crop production intensification		Crop production extensification	
	1961	2005	2005	2005
Standard of living		improved	same as RW	same as 1961
Crop yield, t/ha	1.84	3.96	1.84	1.84
Crop production, million tons	1,776	4,784	4,784	3,811
Agricultural tractors, million	11.3	28.5	28.5 [1]	23.7
Irrigated area, million ha	139	284	284 [1]	298
Fertilizer (N-P_2O_5-K_2O) application rates, kg/ha	32	136	32	32
Global fertilizer consumed, million tons	31	165	88	67
Cropland area expansion since 1961, million ha	-	248	1,761	1,111
Net increase in GHG emissions compared to RW, Gt CO_2e			**590**	**317**

[1] AW1 conservatively assumes machinery use and irrigation area remained the same as in the RW.

Approx. 100x annual CO_2-e GHG emissions in U.S → **590**

Each dollar invested in higher crop yields has resulted in 68 fewer kg of C (249 kg CO_2e) emitted.

Total global GHGs in 2006 = 41,755 Mt CO_2e (or 41.76 Gt CO_2e)

Snyder et al. 2010 Better Crops 4:16-17, citing Burney et al. 2010. Proc. Natl. Acad. Sci. 107(26):12052-12057

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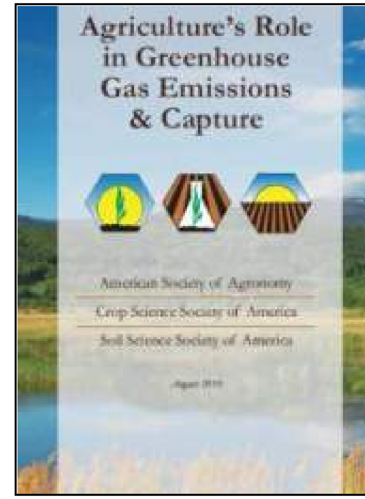
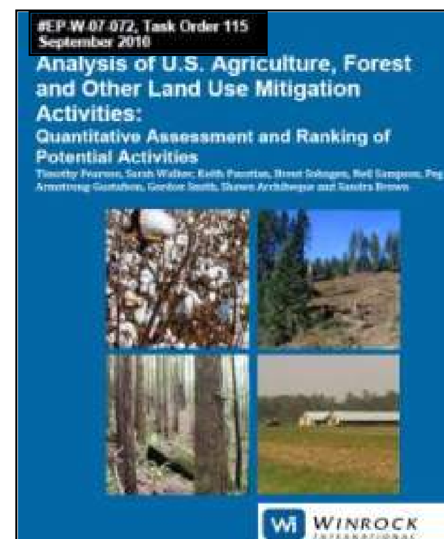
GHG Emissions – Ag Mitigation Protocol



- **N**itrous Oxide **E**mission **R**eduction **P**rotocol
  - Approved – Alberta, Canada (Oct. 2010)
  - Under development – eastern Canada
- **C**limate **A**ction **R**eserve Scoping Meetings
  - Chicago, IL; Modesto, CA; Washington, DC (Oct. 2010)
- **A**merican **C**arbon **R**egistry (Nov. 23, 2010)
  - approves innovative agriculture sector methodology for GHG emission reductions through changes in fertilizer management



CONCLUDING STATEMENTS

- Balanced fertilization enhances N use efficiency and effectiveness
- Appropriate fertilizer N use increases crop biomass to help restore/maintain/increase soil organic carbon (SOC)
- Reductions in soil disturbance and maintenance of crop residue on soil surface through conservation or reduced tillage can increase SOC

CONCLUDING STATEMENTS

- N_2O emissions vary among N sources depending on site-specific conditions, weather, and cropping systems (crops, rotations, tillage)
- Intensive crop management (ecological intensification) does not necessarily increase GHG emissions, especially per unit of food produced
- **Intensive crop management**, using research-based fertilizer management, has resulted in avoidance of enormous GHG emissions – **a critical provision of ecosystem services**

Thank You

Better Crops, Better Environment … through Science

www.ipni.net